

Method and device for control of the operation
of a nitrogen oxides trap for an internal
combustion engine running on lean mixture.

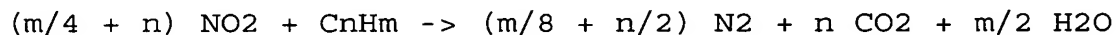
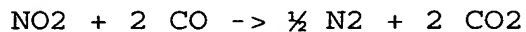
The present invention relates to a method and a device for control of the operation of a nitrogen oxides trap for an internal combustion engine running on lean mixture.

More particularly, it is intended for diesel engines, or in general for engines whose operation takes place under conditions of emission of exhaust gas with relatively low richness.

The use of catalysts of the nitrogen oxides trap type, also commonly known as "Nox Trap", is already known in diesel engines. It corresponds to the desire to avoid discharge of nitrogen oxides in the exhaust gases, since the emission of nitrogen oxides at the engine outlet is increasing with the current attempts to run the engines on lean mixture, that is under conditions of excess oxygen relative to the fuel and therefore excess air. In other words, in this type of operation with lean mixture, the richness at the intake is lower than 1, the value corresponding to a stoichiometric mixture.

During operation of the engine, a nitrogen oxides trap continuously captures the nitrogen oxides contained in the exhaust gases produced by the said engine. It is therefore necessary to regenerate the nitrogen oxides trap periodically in order to unburden it, which is achieved by an operation known as purging, during which

the nitrogen oxides content is reduced. It is known to perform this purging periodically, temporarily commanding the richness of the engine to be increased, in such a way that the richness of the exhaust gases upstream from the nitrogen oxides trap is greater than 1 and that the oxygen concentration is low, that is, such that the engine generates reducing agents such as HC, CO and H₂, capable of reducing the nitrogen oxides stored on the substrate of the trap, by means of the following reactions:



Termination of the purging can be commanded, for example, at the end of a predetermined time after the engine was changed over to running on rich mixture. However, that does not make any allowance for the real burden of the nitrogen oxides trap, and there is the risk that either purging will be incomplete or that the phase of running on rich mixture will be impractically long.

The object of the present invention is to overcome this problem and in particular to provide a method and means with which it is possible, in optimal manner, to command a stop to purging of a catalyst of the nitrogen oxides trap type disposed in the exhaust line of an internal combustion engine that normally runs on lean mixture.

With these objectives in mind, the object of the invention is a method for control of the operation of a nitrogen oxides trap for an internal combustion engine running on lean mixture, wherein purging of the said nitrogen oxides trap is commanded periodically.

According to the invention, this method is characterized in that a first oxygen sensor is disposed in the exhaust pipe downstream from the nitrogen oxides trap, and the evolution of a meaningful signal representative of the signal delivered by this sensor is observed, a substantial increase of this meaningful signal from a first plateau of substantially constant level, reached following a variation subsequent to a changeover of the engine from running on lean mixture to running on rich mixture, being used as the indicator to command the end of purging.

In the method according to the invention, the command to end purging of the nitrogen oxides trap is therefore achieved in response to a notable evolution of the meaningful signal representative of the condition of the oxygen sensor disposed downstream from the trap, this evolution comprising a marked increase of the signal beyond a first plateau reached practically as soon as the beginning of purging and at which the signal had previously substantially stabilized. The inventors in fact observed that, under substantially constant conditions upstream from the nitrogen oxides trap during purging, the signal delivered by the oxygen sensor disposed downstream from the nitrogen oxides trap still underwent a meaningful evolution at the moment when the

reduction of all stored nitrogen oxides was sufficiently complete.

One difficulty encountered was actually that, in the case of engines running on lean mixture, such as diesel engines, the signal of an oxygen sensor disposed downstream from the nitrogen oxides trap shoots up almost immediately, as soon as purging is initiated, and that therefore this premature upward shoot obviously could not be used to indicate the end of reduction of the nitrogen oxides stored in the nitrogen oxides trap.

It is recalled here that lambda sensors normally deliver a signal that is practically binary as a function of whether or not oxygen is being detected. Proportional sensors are certainly more suitable for measuring a range of concentrations or progressive variations, but the signal that they are capable of delivering nevertheless varies abruptly if the evolution of the oxygen content is strong and fast.

For engines running on lean mixture, the initiation of purging, which takes place by changeover to a substantially richer mode of operation in order to provide reducing elements capable of reacting with the stored nitrogen oxides, leads to a large excess of HC in the gases passing through the nitrogen oxides trap and arriving immediately at the downstream sensor, which itself reacts almost immediately by reaching saturation.

It was known beforehand, in the case of a gasoline engine running on lean mixture, that the upward shoot of the signal of the sensor indicated the disappearance of

oxygen at the outlet of the nitrogen oxides trap, which therefore could be interpreted as the end of purging, that is, the arrival again of a reducing mixture at the sensor, whereas previously, during purging, the reducing agents originating from the engine were being consumed by the reduction reactions used for purging. In fact, in this case, the proportion of CO to HC in the exhaust gases is relatively high, but, since the reducing power of CO is much stronger than that of HC, a kind of equilibrium is established between the aforesaid reduction reactions, leading to a substantially equivalent participation of all reducing agents delivered by the engine in purging of the nitrogen oxides trap. As a result, the gaseous mixture exiting the nitrogen oxides trap then remains without effect on the sensor while these reactions are occurring, and it is only at the end of the reduction reactions that the reducing agents are then present in excess at the outlet of the nitrogen oxides trap, causing the sensor signal to shoot up, since it is then truly representative of the end of purging.

In contrast to the foregoing, it became apparent to the inventors that, in the case of the engines considered by the present invention, operating with a richness on the order of 1 to 1.1, the upward shoot of the signal takes place almost as soon as purging begins following the relatively massive arrival of HC at the sensor disposed downstream from the nitrogen oxides trap. An explanation of this phenomenon, which does not occur in the case of operation with greater richness, such as 1.2 to 1.4, appears to lie in the fact that the HC/CO ratio is higher in the exhaust gases in the case of operation with lower richness. In fact, the evolution of CO content

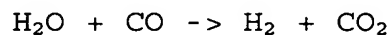
as a function of richness is exponential, while it is linear for HC. Now, since the reducing power of H₂ and of CO is greater than that of HC, the purging reactions will therefore take place preferentially with these H₂ and CO reducing agents but, because of the relative excess of HC, the equilibrium of reactions mentioned in the foregoing no longer is established, thus leading to the presence of unreacted HC at the outlet of the nitrogen oxides trap practically as soon as purging begins. The variation of the signal delivered by the sensor therefore no longer is indicative of the total reduction of the nitrogen oxides contained in the nitrogen oxides trap, but to the contrary is evident as soon as purging begins.

The inventors therefore searched for another means of detecting this end of purging. They discovered that, surprisingly, since in particular the lambda sensors are considered to deliver a quasi-binary signal, this signal delivered by an oxygen sensor underwent a new variation starting from a substantially constant plateau at which the arrival of the HC had caused the signal to shoot up as soon as purging began.

An analysis of this phenomenon led to the observation that, after the signal arrived in this way at the level of the first plateau and was maintained there during purging as long as the aforesaid reduction reactions did not treat the majority of the nitrogen oxides stored on the catalyst substrate of the nitrogen oxides trap, this signal shifted to a second plateau of higher level, substantially at the moment of the end of the said reduction reactions, and then remained at this

level as long as the engine continued to run on rich mixture. The inventors then imagined taking advantage of this evolution of the shift of the signal from the first to the second plateau as an indicator of the end of purging and thus for commanding automatically the return to running the engine on normal mixture, that is, on lean mixture.

One explanation of this phenomenon is that, during the purging phase, the quantity of hydrogen downstream from the nitrogen oxides trap is close to zero, because the hydrogen upstream is consumed almost completely by the catalytic reactions, the reducing power of H₂ being predominant, as already indicated hereinabove. When the reduction reactions are terminated by virtue of the small residual quantity of nitrogen oxides stored in the nitrogen oxides trap, the HC, CO and H₂ reducing agents will be found in increasing concentration downstream from the nitrogen oxides trap and simultaneously will favor the formation of H₂ within the nitrogen oxides trap via various mechanisms, including in particular:



This formation of H₂ was measured by gas-phase chromatography and continuous mass spectrometry.

This modification of the concentration of reducing agents downstream from the nitrogen oxides trap influences the signal of oxygen sensors of all-or-nothing type, such as the lambda sensors or the sensors of proportional type, such as the sensors known under the

name of UEGO[®] sensor, which then present a signal in the form of the said second plateau situated at a level higher than the first plateau. The oxygen sensors of the lambda type and the oxygen sensors of the proportional type are particularly sensitive to hydrogen present in the exhaust gases, and they exhibit a large variation of their signal when the H₂ concentration in the exhaust gases changes and therefore during the shift from the first to the second plateau.

This particular feature therefore made it possible to take advantage of the variation of the signal from its first plateau to detect the end of purging and consequently to command the engine to return to running on poor mixture, if necessary with a certain time delay after detection of the variation proper.

According to a particular arrangement of the invention, there is additionally used a second oxygen sensor disposed upstream from the nitrogen oxides trap, in order to deliver a reference signal relative to which the evolution of the signal delivered by the first sensor is compared in order to deliver the said meaningful signal. The use of this reference signal, which can be influenced by variations of the operating conditions of the engine independent of those programmed for the purging operation proper, therefore makes it possible, by comparison, to reliably detect the variation that is indicative of the end of the reduction reactions in the nitrogen oxides trap.

In addition, with oxygen sensors of the same type

upstream and downstream from the nitrogen oxides trap, for example two lambda sensors or two proportional sensors, the sensitive element of which is temperature-controlled or else the signal of which is corrected as a function of the temperature of the sensitive element, the higher H₂ concentration in the gases downstream than in the gases upstream from the nitrogen oxides trap is manifested by a higher signal for the sensor situated downstream than for the sensor situated upstream when the reduction of the stored nitrogen oxides is sufficiently advanced:

As a function of the H₂ concentration upstream, and in the case in which two lambda sensors are used, the signal of the upstream lambda sensor can be at the same level as the signal of the downstream lambda sensor at the second plateau.

Traditionally, the oxygen sensor or sensors will be chosen from among the sensors of the following type: sensor of lambda type, proportional oxygen sensor, nitrogen oxides detector, in which the capability of measuring the oxygen concentration is used.

In the case of use of a sensor upstream and of a sensor downstream from the nitrogen oxides trap, it will also be possible for the two sensors to be of different types, and particular, it will then be possible to use, for the purposes of the invention, sensors that may already be installed in the exhaust line to perform other functions. In particular, it will be possible to use the different combinations listed in the following table.

Upstream sensor	Downstream sensor
Proportional sensor	Lambda sensor
Proportional sensor	O2 function of the Nox detector
Lambda sensor	Proportional sensor
Lambda sensor	O2 function of the Nox detector
O2 function of the Nox detector	Lambda sensor
O2 function of the Nox detector	Proportional sensor

where "O2 function of the Nox detector" denotes the use of the oxygen-concentration measuring function of a nitrogen oxides detector, as indicated in the foregoing.

When two oxygen sensors of different nature are used, it is necessary either to introduce a transfer function between the sensor signals (taking into account any differences in response times) or to use cells equivalent to that of the lambda sensor.

According to a first embodiment, the increase of the meaningful signal is detected by applying filtering of the first derivative of the meaningful signal and by comparing the filtered first derivative with a predetermined threshold.

According to a second embodiment, the increase of the meaningful signal is detected by applying filtering of the second derivative of the meaningful signal and observing the passage of the filtered second derivative through zero in decreasing threshold.

According to a third embodiment, the increase of the meaningful signal is detected by taking the difference between the instantaneous value of the meaningful signal and a sliding mean of the said signal, and by comparing this difference with a threshold.

According to a fourth embodiment, the increase of the meaningful signal, for a lambda sensor, is detected by comparing the voltage value delivered by the sensor with a predetermined threshold.

A practical example of the invention will now be described for a diesel engine.

Reference will be made to the attached drawings, wherein:

- Fig. 1 is a schematic and partial representation of the gas circuit of the said engine,
- Fig. 2 is a graph that shows the curves representative of the signal of different sensors disposed upstream and downstream from the nitrogen oxides trap, and that illustrates the variation of the signal used as indicator of the end of purging.

On Fig. 1 there are schematically represented the elements of the engine through which the gases pass, and there are seen therein, successively in the direction of flow of the gases:

- inlet 11 for air arriving from the air filter,
- suction part 12 of a turbocompressor,
- intake manifold 13,
- the upper part of cylinder 14, equipped with an

injector 15,

- exhaust tubes 16 and the exhaust part 17 of the turbocompressor,
- nitrogen oxides trap 18,
- the exhaust line, equipped with a particle filter 19.

A first oxygen sensor 21 is mounted downstream from the nitrogen oxides trap, and a second oxygen sensor 22 is mounted upstream from the nitrogen oxides trap, the two sensors being connected to a calculating unit 23, which itself is connected to an engine-control unit 24.

Sensors 21 and 22 are, for example, proportional or lambda sensors.

The graph of Fig. 2 shows the results of test measurements performed with different types of sensors as a function of the time from initiation of purging. On the ordinate, the left scale represents the value of the signal delivered by a sensor, and the right scale represents the quantity of CO downstream from the nitrogen oxides trap (for trace 6).

Line 3 represents the signal delivered by a sensor of lambda type disposed downstream from the nitrogen oxides trap. On the line there is clearly seen the upward shoot 31 of the sensor as soon as purging begins, and the first plateau 32 which remains substantially stable during purging, then the marked variation 34 of the signal, representative of the arrival of H_2 at the sensor and is therefore indicative of the end of purging, before the signal restabilizes at a second plateau 33.

Line 4 represents the signal delivered by a sensor of proportional type disposed downstream from the nitrogen oxides trap. On the line there is clearly seen the upward shoot 41 of the sensor as soon as purging begins, and the first plateau 42 which remains substantially stable during purging, then the marked variation 44 of the signal, representative of the arrival of H_2 at the sensor and is therefore indicative of the end of purging, before the signal restabilizes at a second plateau 43.

In comparison, line 5 represents the signal delivered by a sensor of proportional type disposed upstream from the nitrogen oxides trap. It is clearly seen that this signal also undergoes an abrupt rise 51 at the moment of initiation of purging, due to the influx of reducing agents in the exhaust gases. In contrast, the signal then remains constant on a plateau 52, as long as the engine is maintained under constant conditions of running on rich mixture. In the event of any perturbation whatsoever of these conditions during purging, that perturbation will correspondingly affect both the upstream sensor and the sensor situated downstream from the nitrogen oxides trap, and it will be possible to use this signal delivered by the upstream sensor as a reference for evaluating, by comparison, the variations of the signal of the downstream sensor, truly indicative of the end of purging.

It will also be noted that the level of plateau 42 is situated below plateau 52, the difference corresponding to the fraction of the reducing agents used to reduce the nitrogen oxides stored in the filter. In contrast, when purging is terminated, the signal of the

downstream sensor shifts above that of the upstream sensor, clearly illustrating the arrival at the sensor of the hydrogen formed in the nitrogen oxides trap by the aforesaid reaction mechanism.

On this graph there was also represented a line 6 representing the evolution of the CO content downstream from the nitrogen oxides trap, measured in experimental manner, and the evolution of which, marked by the strong increase 61 at the moment when the sensor signals shift from the first to the second plateau, clearly corroborates the end of consumption of the said CO for reducing the nitrogen oxides stored in the nitrogen oxides trap, and therefore the advanced disappearance thereof.

As an example of how the signal obtained from the sensors is processed, there was also represented in the graph the line 7, which represents the filtered first derivative of the signal, and illustrates the possibility of detecting the end of purging by comparing this signal with a predetermined threshold, crossed by the said derivative during its abrupt increase 71, corresponding to the increase of the slope of the signal obtained from the sensor.

Similarly, there was also represented the line 8, which represents the second derivative, whose passage through zero in decreasing threshold 81 can also be used as information indicative of the end of purging.

The invention is not limited to the examples described hereinabove. It is intended more particularly for diesel engines, but it could also be applied in

general to all engines that normally run on lean mixture.